Evaluation and mapping of relative sensitivity of the terrestrial ecosystems to acidic deposition in Fujian[1]

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Abstract Based on the semi-quantitative approach, four environmental factors of sites (i.e. bedrock lithology, soil type, land use, and rainfall) were categorized, weighted and combined to determine and assess the relative sensitivity of the terrestrial ecosystems to acidic deposition in Fujian Province. Then the factors have been digitized and combined to assign an overall value for each mesh square (16.77 km ×18.39 km) by using the geographic information system (GIS) The results indicated that the most sensitive area in Fujian was mainly located in the southeast, and the least sensitive area was distributed sporadically in the east along the coast. Due to slow weathering rate of siliceous rocks, acid to weakly acid reactions of the soils, along with the greater percent of coniferous forests, more than 80 percent of the total area exhibits higher sensitivity classes (4-7).

Key words: Acidic deposition, Terrestrial ecosystem, Relative sensitivity, Mesh map

Introduction

As human's consumption for fossil fuels increases, more and more air contaminants are being emitted into the atmosphere, and eventually may be transferred to the surfaces of soil in terrestrial ecosystems by dry deposition and precipitation scavenging (Abeles *et al.* 1971; Smith 1981; Matzner & Prenzel 1992; Kreutzer *et al.* 1998). Under humid climate soil formation process for itself is an acidifying process due to natural cation leaching (Frink & Voigt 1976). However, many experiments subjecting soil lysimeter to natural or artificially acidified rainfall showed that acid precipitation accelerated the soil leaching process (Mayer & Ulrich 1976; Cronan *et al.* 1978; Rustad *et al.* 1993; Kurz *et al.* 1998). As the more easily dissolved constituents such as calcium, potassium, magnesium and sodium are removed in solution; the soil system becomes more and more dominated by hydrogen and aluminium ions (Frink & Voigt 1976; McLaughlin & Tjoelker 1992).

Fujian Province lies in the southeastern part of China, ranges between 23°30′-28°22′ north latitude and 115°50′-120°43′ east longitude, covering an area of about 1.215×10^5 km^2. The soils are characterized by a lower cation exchange capacity, lower base saturation degree, and with an organic matter content of 2%-5%, occasionally up to over 10% in the topsoil, showing a higher sensitivity to acidic depositions (Lin *et al.* 1991; Fan & Gao 1993).

With the increasing consumption for coal resources in Fujian Province, emissions of sulphur dioxide are becoming an environmental problem, resulting in high rates of sulphur deposition, which is affecting terrestrial ecosystems (Song 1996). But up to the present, effects of acid deposition have received few studies in China, and no general criteria were devel-

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oped for assessing sensitivity of ecosystems to acid deposition (Feng 1993; Zhou & Qin 1992). Based on the semi-quantitative method (Chadwick *et al.* 1991), four site factors were selected in this paper to determine the relative sensitivity of the terrestrial ecosystems to acidic deposition in Fujian Province, and the mesh maps within this area were made by using ARC/INFO geographic information system.

Methods

Categorization of site factors

The site factors used to determine the sensitivity of the soils to acidic deposition were: rock type, soil type, land use and rainfall. These factors were selected because of their relevance to site responses to acidic deposition, the general availability of information, their susceptibility to mapping procedures, their overall integrative nature, the relative unambiguous acceptance of what they represent and the relative permanence of applicability to an area. Other factors of importance such as soil depth and sulphate adsorption capacity did not meet some of the criteria, and their use was therefore not attempted.

Division of site factors into categories and the associated weights were given in Table 1.

Rock type

Rock types were classified into two categories based on their weathering rates. However, in the Soil Atlas of China (Hseung 1986), information on rock types can only be found in Map of Soil Parent Materials of China. Therefore, types of parent materials were used for evaluation on bedrock lithology in this paper. The main parent rocks producing soil materials in Fujian were shown in Table 2.

Table 1. Division of site factors into categories and associated weights

Factor	Weight	Category	Weighting
Rock type	2	Ⅰ slow weathering rocks	1
		Ⅱ faster weathering rocks	0
Soil type	1	Ⅰ surface soil pH <5.0	1
		Ⅱ surface soil pH >5.0	0
Land use	3	Ⅰ coniferous forest	1
		Ⅱ shrubbery	2/3
		Ⅲ hardwood forest	1/3
		Ⅳ arable land	0
Rainfall	1	Ⅰ annual average >1 400 mm	1
		Ⅱ annual average <1 400 mm	0

Table 2. Main parent rocks producing soil materials in Fujian

Group	Soil Material	Main Parent Rock
A	Weathered materials of light coarse crystalline rocks	Granite, gneiss, diorite
B	Acid alluvium	Kaolinite, vermiculite and montmorillonite
C	Weathered materials of sandstone and shale	Conglomerate, sandstone, shale, schist, phyllite, slate, and coastal marine deposits
D	Weathered materials of limestone	Limestone, dolomite and marble

The weathered materials of light crystalline rocks were weathered products formed during Mesozoic era, rich in silica and light minerals, known as the major parent materials for red earths, and lateritic red earths. Soils developed on such materials were poor in mineral nutrients and mostly had an acid reaction. Parent rocks producing the materials included granite, gneiss and diorite as shown in Table 2.

Lying on the eastern part of Fujian, the acid alluvial deposits were the soil-forming parent materials of paddy soils and cultivated fluviogenic soils, dominated by kaolinite along with a less amount of vermiculite and montmorillonite.

The weathered materials of sand stone and shale had a wide distribution range in the mid-western part of Fujian. Major rocks producing the materials were conglomerate, sandstone, shale, schist, phyllite and slate. Coastal marine deposits were mainly distributed in the coastal regions of Fujian, known as a mixed group of marine and terrestrial deposits with a considerable amount of chloride.

The weathered materials of limestone were only confined to a very small area of central Fujian, containing abundant carbonate and elements such as calcium, phosphorus, etc.. The weathered materials developed under slow-weathering rock types (Groups A and B in Table 2) displayed a low ability to neutralize acids due to limitation rate of parent rocks and constitute Category Ⅰ. The other weathered materials with a higher ability to neutralize acids (Groups C and D) were assigned to Category Ⅱ.

Soil type

Soil buffering capacity was mainly dependent on cation exchange capacity, base saturation and exchangeable calcium content. Soil pH is considered to reflect the situation of these capacity parameters and to give an indication of the current soil chemistry. Research showed that a soil with pH value below 5.0 because increased aluminium mobilization engendered toxicity to the roots (Lin *et al.* 1991; Song 1996). Therefore, soil types with pH value of below 5.0 will increase site sensitivity and are assigned to Category

I as shown in Table 1. Other soil types with pH above 5.0 are assigned to Category II.

The soil types assigned to Category I include lateritic red earth, yellow earth, acid purplish soil, and some subgroups of red earth. Red earth, mountain meadow soil, neutral purplish, limestone soil, coastal sandy soil, solonchaks, and paddy soil are assigned to Category II.

Main chemical parameters for soil types in the two categories were listed in Table 3.

Table 3. Main parameters of the soil data for the two soil categories in Fujian

	Soil category	PH	CEC /cmol · g^{-1}	Organic matter content (%)	Base saturation	Sand (>0.01mm) (%)
I	Mean[a]	4.68	14.03	3.81	—[b]	54.96
	S.d.[c]	0.08	2.45	2.21	—	7.55
	Range	4.37-4.94	5.02-20.65	1.84-7.24	<20	40.44-83.75
II	Mean	5	9.08	3.98	—	47.79
	S.d.	0.15	1.67	0.89	—	5.44
	Range	5.00-7.80	0.34-26.88	0.11-12.63	20-60	35.73-94.03

Notes: [a]-- Area weighted average; [b] --Means no complete data; [c] --S.d. =standard deviation.

Land use

Since the late 1960s of this century, the area of artificial coniferous forests (mainly Chinese fir and Masson pine plantation) in nearly pure stands has been increasingly expanded around Fujian Province. Repeated planting with a single coniferous species at the same site caused severe soil degradation and nutrient deficiency because of the formation of the typical acid mor organic layer and slow release of nutrients from organic matter under coniferous plantation. The barren land usually formed following repeated clear-cutting of the forests and slash-burning of the cutover site experienced great soil erosion hazards. Therefore, coniferous plantation and barren land were collectively considered to increase site sensitivity most as shown in Table 4.

Table 4. Included land use types in land use categories

Category	Included types of land use
I Coniferous forest	Chinese fir and Masson pine plantation, barren land
II Shrubbery	Shrubbery, sparse distributed forest, range land
III Hardwood forest	Evergreen broad-leaved forest, bamboo stand
IV Arable land	Arable land, economic forest

Following reclamation on steeply sloping sites, mismanagement of the land, and rough grazing by removal of the forests, the shrubbery and mixed community of grasses and shrubs were developed on the mountainous areas. Mor humus appeared also under this type of vegetation. So shrubbery vegetation ranks second in weighting and constitutes Category II.

Mull forest floors are usually developed under hardwood forest vegetation because of a rapid and complete decomposition of litter in subtropical climate of Fujian. Bamboo stands (mainly *Phyllostachys pubescens*) is a widely distributed vegetation type, which occupies about 12% of the forested areas in Fujian. Study showed that bamboo stands produced a humus layer with abundant mineral nutrient contents (e.g. K, Ca) and faster decomposition rate of litter (Fu 1989), which were equivalent to hardwood forest. Accordingly, sites under hardwood forests and bamboo stands had a lower sensitivity to acidic deposition and were assigned to Category III.

Economic forest was a special type of plantation which was established and administered for producing fruits, edible oils, perfumes, industrial resources with a special use (e.g. lacquer, tannin extract, etc.). Economic forestland, as arable land, was usually intensively managed on which fertilization was regularly used. Economic forest land and arable land are considered to reduce sensitivity and collectively assigned to Category IV.

Rainfall

The average annual rainfall ranges from 1 100 mm along coastal areas to 2 000 mm both in the regions of Wuyi Mt. and northern mountainous areas in Fujian Province. Greater rainfall usually occurs in mountainous areas because of formation of orographic precipitation.

The chemical composition of soil is strongly affected by its water relationships (Kimmins 1987). In southeast China, evaporation usually exceeds precipitation, resulting in leaching of chemicals from soils. Warm climate and high rainfall in Fujian increased leaching of base cation, leading to acidification of the soils. Therefore, areas with a mean annual rainfall of greater than 1 400 mm were considered to have a higher sensitivity than those with less.

Mapping relative sensitivity

The factors used in the evaluation of relative sensitivity have been digitized so that they may be combined using the geographic information system (Burrough 1986; Tomlin 1990). Parent materials were digitized from Soil Atlas of China (Hseung 1986). Soil types were digitized from Soil Map of Fujian Province (Lin *et al.* 1991), with Map of Soil pH of China for reference (Hseung 1986). Land use types were digitized from Forest Resources Map of Fujian Province (by permission of Fujian Forest Survey Institute, drawn in 1992). Rainfall was digitized from Rainfall Distribution Map of Fujian Province (Lin *et al.* 1991).

To make the mesh map of relative sensitivity to acidic deposition, the maps of rock, soil, land use, and rainfall were divided into square mesh with each ten minutes along latitude and longitude, respectively. The size of square mesh made in this way corresponds to 16.77 km in latitude and 18.39 km in longitude, with an area of 308.35 km^2. For the mesh maps of the four site factors, the characteristic value in each mesh was determined by the weights assigned to the category occupying the greatest area.

Results and discussion

Eight relative classes (0-7) were the result of combining the four factors at the range of weightings assigned as shown in Table 1. Then the relative sensitivity to acidic deposition was mapped by using ARC/INFO geographic information system (Fig. 1).

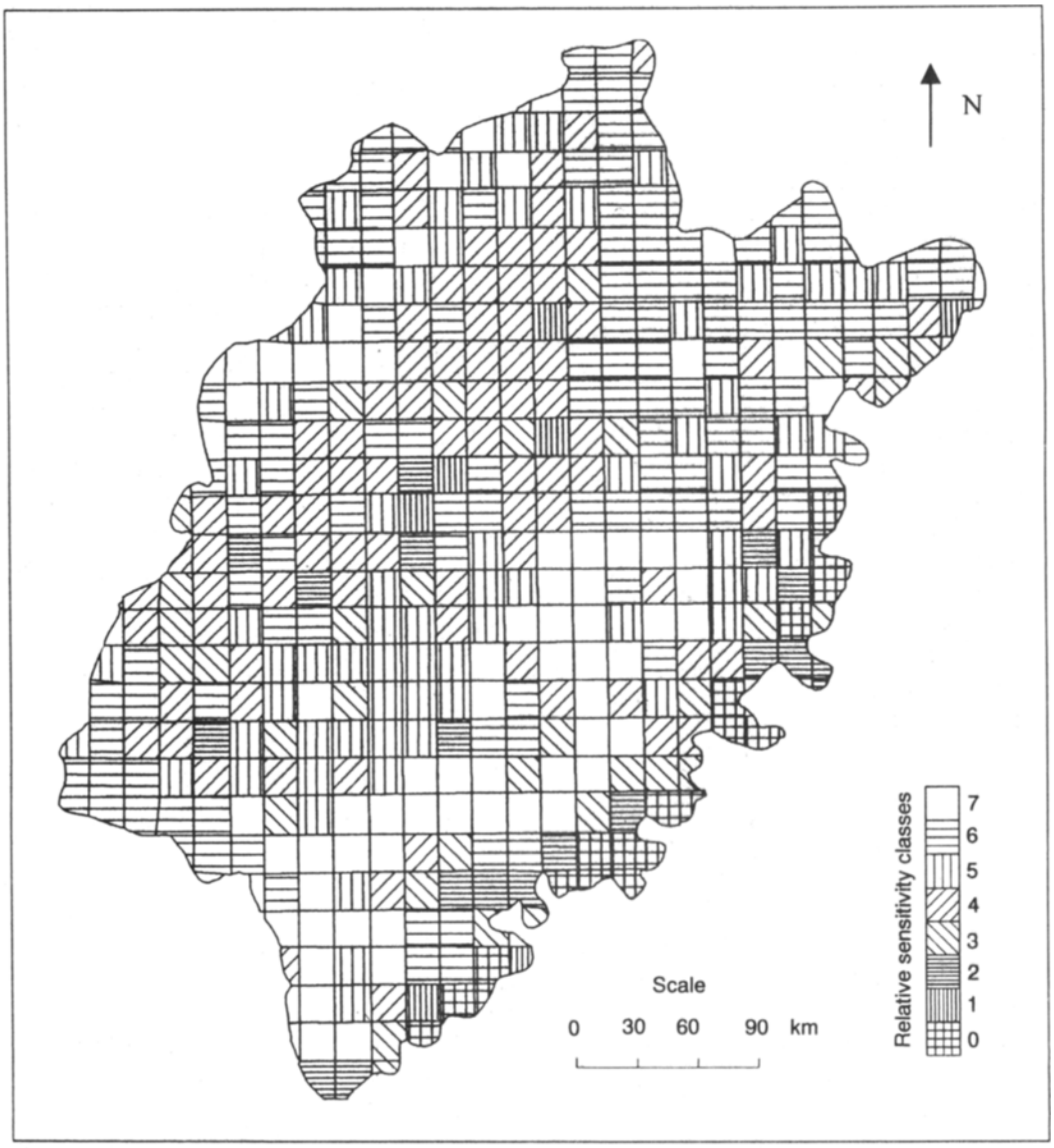

Fig. 1. Division into the relative sensitivity classes of terrestrial ecosystems to acidic deposition in Fujian

The area covered by each sensitivity class is listed in Table 5. Due to slow weathering rate of siliceous rocks, acid to weakly acid reactions of the soils, combined with the greater percent of coniferous forests and barren land, more than 80% of the total area of Fujian Province exhibits higher sensitivity classes (4-7).

Table 5. The covered areas for each sensitivity class in Fujian

Sensitivity class	Covered area /km^2	Area percent (%)
7	19 136.20	15.75
6	33 665.65	27.71
5	21 075.72	17.35
4	25 300.12	20.82
3	11 535.37	9.49
2	5 038.44	4.15
1	2 028.94	1.67
0	3 721.78	3.06
Total	121 502.22	100

From the practical point of view, evaluation on soil sensitivity to acidic deposition is of great significance in China (Feng 1993). In recent years, some studies on the sensitivity of soil and surface water to acid deposition proved to be meaningful (Zhou & Qin 1992; Jiang *et al.* 1992). However, the existing national data are not sufficient to apply "Level 1" steady state approaches, "Level 0" approaches should have a potential for application nationwide in assessing the sensitivity of ecosystems to acidic deposition.

The buffering capacity of the soils to acidic deposition is not only dependent on soil properties, but also on other environmental factors which are relevant to site response to acidic deposition (Chadwick *et al.* 1991). By choosing different parameters as the bases for ranking sensitivity, no general criteria are still established (McFee 1980). However, all the researchers considered that any one factor alone would not give a sufficiently accurate indication of sensitivity. For example, the soil type that forms at a site is not only influenced by the parent material but also by climate and land use practices.

The response of the soil to acidic deposition may also be modified by these factors. Thus, four site factors appear to be a minimum combination that needs to be employed to arrive at a "finely-tuned" assessment of relative sensitivity (Chadwick *et al.* 1991). There still need further studies on how many factors should be selected and how to categorize and weight these factors to arrive at a more objective assessment of sensitivity.

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